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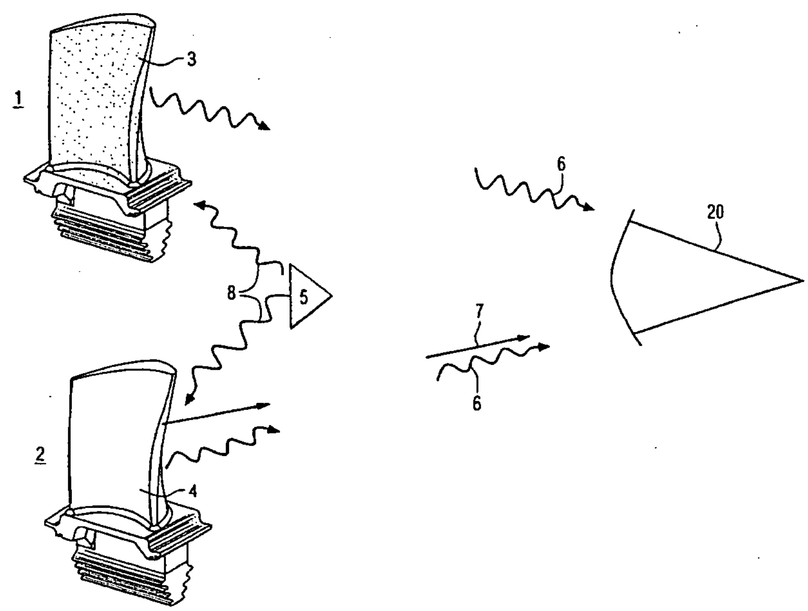
(54) Title: METHOD AND APPARATUS FOR MEASURING ON LINE FAILURE OF TURBINE THERMAL BARRIER COATINGS



(57) Abstract: A method of remotely monitoring the radiant energy (6) emitted from a turbine component such as a turbine blade (1) having a low-reflective surface coating (3) which may be undergoing potential degradation is used to determine whether erosion, spallation, delamination, or the like, of the coating (3) is occurring.

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METHOD AND APPARATUS FOR MEASURING ON LINE FAILURE OF TURBINE THERMAL BARRIER COATINGS

GOVERNMENT CONTRACT

The Government of the United States of America has rights in this invention pursuant to Contract DE-AC05-95OR22242 awarded by the United States Department of Energy.

BACKGROUND OF THE INVENTION

Field of the Invention

The invention relates to means to identify, monitor and take action upon potential delamination of ceramic coatings used as a thermal barrier for turbine components.

Background Information

Cobalt or nickel based superalloys of, for example, IN738, or ECV768 are used for making blades, vanes and other components of gas turbines. These turbines can operate at temperatures in the range of 1000□C to 1600□C and are generally protected by a series of protective coatings. The coatings usually comprise layers of metallic base coats, service formed aluminum oxide layers and a final ceramic thermal barrier coating ("TBC"). The TBC is usually made of yttria, ceria or scandia stabilized zirconia, as taught, for example, by U.S. Patent Specification Nos. 5,180,285; 5,562,998; 5,683,825 and 5,716,720 (Lau, Strangman, Bruce et al., and Murphy, respectively). Long term exposure of these ceramic coatings to the hostile, high temperature, abrasive environment in which such turbines operate can cause phase destabilization, sintering, microcracking, delamination and ultimately spallation within the coating layers, exposing the superalloy component to degradation or failure and requiring expensive repairs.

Many attempts have been made to non-destructively test such coated superalloy metal surfaces for non-obvious, subcoating degradation. U.S. Patent Specification No.

4,647,220 (Adams et al.) teach a system to detect corrosion and stress corrosion cracking of painted metal structures, utilizing infrared thermographic techniques to detect temperature differentials caused by the difference in thermal conductives between corroded metal and uncorroded metal. A scanner can be used to produce a television-compatible, video output signal of the thermophysical characteristics it is viewing. This system is used primarily on stationary military aircraft. U.S. Patent Specification 5,294,198 (Schlagheck) teaches a system to determine defects in commercial products by obtaining an infrared image of the product while it is being stimulated. An infrared television monitor supplies a signal to a color monitor where hot or cold temperature regions appear as red or blue respectively. Defects can be determined by an inspector or a computer. This system can also be incorporated into production lines, and eliminates prolonged vibration and/or temperature cycling as tests of commercial products.

In U.S. Patent Specification No. 5,272,340 (Anbar) teaches an infrared imagining system which simultaneously generates temperature, emissivity and fluorescence, for use in clinical diagnosis and management of skin disorders, to determine true skin temperature as a tool in the treatment of malignancies, burns and the like. U.S. Patent Specification No. 5,608,845 (Ohtsuka et al.) relates to predicting the remaining lifetime, by parts degradation analysis, of, for example, carbon seals, electrically operated values, control rod drivers, and the like, in locations such as electric power plants. This appears to be accomplished by establishing a series of lifetimes based on experimental aging degradation data.

In U.S. Patent Specification No. 5,552,711 (Deegan et al.), probable turbine blade failure is determined by

measuring specific ions emitted by hot spots. The invention relates to electromagnetic energy radiated by ions that are created as combustion gas erodes and ionizes materials in these hot spots using spectral detectors looking for characteristic ions. However, this system requires failure to occur, for example by melting of components and detection of ions. Turbine blade temperature monitors are taught by U.S. Patent Specification Nos. 5,306,088 and 5,832,421 (Zoerner and Santoso et al., respectively). Zoerner requires an actual fiber-optical cable actually disposed inside a turbine component. Santoso et al. require measurement of pressure and temperature at locations other than the blades and then simulating blade temperature values using a water stream cycle analysis program and then training an artificial network so that it can learn to recognize a failure by estimating blade temperature.

In U.S. Patent Specification No. 4,764,025 (Jensen), a temperature detection pyrometer is used to determine turbine blade temperature from radiation reflected and emitted from the blade. The system substantially reduces the effect of reflected radiation from flame or hot carbon particles. Detected radiation is divided into two channels and the output of one of the detectors is weighted relative to the other. The difference between the factored output from one detector and the output from the other detector is provided to a difference amplifier to provide a signal directly related to the temperature of the turbine blade.

There is still special need, however, to be able to sense potential failure situations for complex, moving turbine components having ceramic coating layers, by utilizing a very fast sensor system. This would require measuring relative spatial/time radiance using an expert system, and some sort of a degradation model that will

generate advisory information and actively avert failure. This system must identify very small hot spots on low-IR, reflective ceramic surfaces, detect spalling and debond areas, measure their growth, and forecast and prevent failure.

SUMMARY OF THE INVENTION

Therefore, it is a main object of this invention to provide a method and apparatus effective to monitor delamination of cooled, low-IR reflective ceramic turbine components which may be in a hostile environment and moving rapidly, so that detection of debond areas or the like within the ceramic, or separate cooling system failures, triggers almost instantaneous means to analyze potential damage and shut down the apparatus if necessary.

These and other objects of the invention are accomplished by providing a method for testing of a cooled, operating turbine component which will contain an exterior protective ceramic thermal barrier coating undergoing potential degradation in a corrosive, high temperature turbine environment and having a low-IR reflective surface, by remote monitoring of radiant energy, to determine any degradation of the cooling system, or of the thermal barrier coating, caused by at least one of erosion, corrosion, sintering, microcracking, spallation and bond delamination; having a database means evaluate said degradation; and optionally modifying the operating parameters of the turbine based on the evaluation of the degradation.

The invention also resides in a method for generating data from non-destructive testing of a turbine component, which is contacted by a cooling medium and which will contain an exterior protective ceramic thermal barrier coating undergoing potential degradation in a corrosive, high temperature turbine environment, by (A) providing an infrared thermal imaging means; (B) providing a data base

means connected to the imaging means to provide a measuring system, the measuring system having at least one sensor effective to quantitatively measure and generate data by using non-destructive, remote monitoring of the surface radiance distribution, without physical contact of the thermal barrier coating, directly at the surface of the thermal barrier coating where such distributions are caused by heat flow within the thermal barrier coating; (C) monitoring the radiance of the measuring system to determine any degradation of the cooling system, or of the thermal barrier coating, caused by at least one of erosion, corrosion, sintering, microcracking, spallation, and bond delamination; (D) having the database means evaluate said degradation; and (E) optionally modifying the operating parameters of the turbine based on the evaluation of the degradation. The turbine component is cooled or contacted by a cooling medium supplied by an associated cooling system, as is well known in the prior art. By "data" is meant: a spatial, registered map of surface radiance of key surfaces of turbine blades. Data is stored and new data is continually compared for spatial differences. By "radiance" is meant: the thermal energy emitted from the surface of the blade. By "evaluate" is meant: to review data for significant events.

The invention also resides in an apparatus for non-destructive testing of a moving turbine component contacted by a cooling medium which component has an exterior ceramic thermal barrier coating undergoing potential degradation in a corrosive, high temperature environment, the apparatus comprising: (I) a measuring system comprising: (A) infrared thermal imaging means, and (B) database means connected to the imaging means, said measuring system being effective to remotely measure and generate data based on the radiance of temperature

distributions on the moving turbine component without physical contact to detect degradation of the ceramic coating, (II) a data base means effective to evaluate said degradation and forecast remaining life as determined by an expert system, (III) means to modify the operating parameters of the turbine based on the evaluation of the degradation, (IV) a means to hypothetically (virtual space) adjust operating parameters to optimize remaining life, and (V) expert system means to determine the optimal operating parameters to maximize life for a given performance need. Preferably, the TBC has a low-IR reflective surface and mostly radiant energy rather than contrainformational reflected energy will be measured. This invention not only allows for the detection of debond, but the ability to watch the debond grow and the ability to know when the debond spalls so that the apparatus can be shut down.

Recent increases in the efficiencies required of land-based combustion turbine engines have not only mandated the use of TBCs on blades and vanes, but, also have made the survivability of these coatings a critical factor in the continuing operation of the turbine. The ability to monitor the structure and status of blade and vane coatings will provide the day-to-day capability to operate the turbine at maximum efficiency and will provide for the timely warning of on-setting or on-going failures, and thereby help avoid the severe repair and maintenance costs that would be incurred by catastrophic vane or blade failures. Today, the U.S. demand for new electrical generating capacity is 13,000 MW per yr. and gas turbines are playing an increasingly important role in meeting this demand in a clean, efficient, reliable manner. Combustion turbine technology is rapidly evolving, and the need to insert new technology is critical to remain competitive in the global market. The development

of an on-line TBC monitor is a crucial technology for advanced turbines.

An effective on-line TBC monitor system would have the following major economic benefits: accelerate the sale of advanced power plants that use advanced turbine engines; improve the reliability of advanced turbine engines by the early identification of the need for TBC maintenance; and accelerate the adoption of advanced upgrade packages to existing turbine engines that can improve plant efficiency; thereby, lowering the cost of electricity.

Some of the novel features of the invention include: (a) thermal imaging for the examination of TBC coated components in motion, (b) the ability to conduct quantitative measurements non-destructively, (c) the ability to conduct these measurements without contacting the component from relatively large distances, (d) the ability to conduct limited measurements without interrupting or with minimal interruption of the operation of the engine, and (e) the ability to make immediate operating decisions in order to minimize risk and damage due to TBC failure. This system could also be used off-line, and would allow nondestructive and noncontact quantitative measurements, for new, service exposed, and service exposed repaired components of: unbonds, thickness, and intrinsic and extrinsic thermal properties while the components are available for direct handling. An off-line remote system would allow remote thermal imaging of critical turbine components with little or no disassembly.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other advantages of this invention will be more apparent from the following description in view of the drawings in which:

Figure 1, is an enlarged view of two turbine blades absorbing heat from a heat source and

radiating/reflecting energy to an infrared thermal imaging camera associated with the remote monitoring means of this invention;

Figure 2 is an enlarged cross-section of a typical turbine blade;

Figure 3 is a block diagram of one method of this invention; and

Figure 4 is a schematic diagram of a blade monitor system utilizing this invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

This invention will provide a means of examining TBC coatings at various stages during the life cycle of the component. In the on-line system, this invention would allow notification within several seconds of debonding and spallation and cooling system failure during the uninterrupted operation of the turbine engine. Furthermore, by tracking the surface temperature in time, long term degradation mechanisms, such as erosion and sintering can be evaluated. This is of key importance with new engine designs where eminent engine failure could occur within minutes of a coating failure.

The invention uses thermal imaging cameras to detect failure of the cooling system used to cool operating turbine components and debonding of coating systems. An external flash or laser heat source is used to initiate a thermal transient for any off-line embodiment. The internal cooling of the blade provides the heat transient for the on-line embodiment. As the heat is conducted through the coating and into the substrate material, the radiance of the local surface is effected. The term "radiance" is hereby defined as the total emittance, in this case, total reflective thermal emittance, from the surface of an object. Emittance is synonymous with radiance, that is, radiant energy emitted by a free surface. Infrared is the region of

electromagnetic spectrum between the microwave and visible. Reflected is electromagnetic energy that undergoes a redirection, with no change in energy upon interaction with a free surface.

Local surfaces of debonded areas exhibit a distinctly different radiance than that of bonded areas because they are hotter. And by similar effect, coating material thickness, thermal conductivity, heat capacity and emissivity will also effect the surface radiance. These effects can therefor be measured and related to the condition of the coating on the component. Preferably, the TBC will have a "low-IR reflective surface" so that radiance is predominant and monitored by an infrared camera leading to more accurate representations of real defect features. The low-IR reflective surfaces usually can be zirconia based TBCs, but can also be zirconia stabilized with transition metal oxides; yttria, scandia, ceria and magnesia stabilized oxides; yttria stabilized zirconia, ceria stabilized zirconia, scandia stabilized zirconia; or non-zirconia based TBC.

When trying to observe a component's radiant thermal energy, if the component is highly reflective, a problem can occur that will result in misreadings. Reflected thermal energy from other objects of higher temperatures can make the object of interest look hotter. An optical light analogy would be to ask ourselves: "what is the color of a mirror." The answer depends on the color of the object being reflected off the mirror. This observation/misreading problem does not happen with low-reflective surfaces. In the low-reflective case, the observed radiant energy is predominantly characteristic of the surface of interest. To better illustrate this point and define the term "low-IR reflective" refer now to Fig. 1 which shows three components: turbine blade 1 with low

reflectance TBC coating 3, turbine blade 2 with high reflectance metallic coating 4, both at 1200°C, and an upstream component 5 that is hotter than 1 or 2 at 1350°C. The hotter component 5 radiates thermal energy 8 that is indicative of the component temperature. This energy can reflect off reflective surface 4 of blade 2 but not off the non-reflective surface 3 of blade 1.

For the preferred on-line embodiment, the components are periodically thermally imaged, and differences of surface radiance are noted and tracked in near real-time operation of the component. Additionally, rapid analysis and decision systems utilizing both expert and supervisory subsystems would be employed to summarize data and make decisions regarding the operation of the turbine. The expert systems would include TBC life and debond growth algorithms that would forecast the operating time available once a debond is detected. The expert system would be interactive to allow the operator or a computer to change turbine operation conditions in virtual space and generate estimates of remaining life of the TBC system.

This invention proposes to address the development of an on-line coating monitor system for TBCs by developing blade and vane monitoring systems and integrating them into a computerized high-speed analysis system that can be installed on an operating turbine. Figure 3 depicts the proposed implementation of this concept. The method will start with developing a clear understanding of the required system capabilities and a correlation with prospective sensor capabilities. The speed capabilities of sensor and computer analysis systems will also be evaluated. The preferred embodiment is based upon a pyrometric sensor array system that will monitor blades as they pass by a single vantage point.

The blade measuring/monitoring system includes sensor 12, signal processor 13, and radiance map or means 14, and will be based upon modification to existing infrared imaging technology.

This technology should be able to achieve the capability to acquire thermal images at sufficient speed and resolution to monitor high-speed events such as the motion of a turbine blade past a viewing port at between 60 and 3600 rpm. It is not necessary to view and acquire images of every blade every time it passes the camera, but it is necessary to acquire a single blade image over a short time interval. Data must be acquired for all blades and then correlated with previous images of that blade. Long term changes would be realized by comparison of current images with older archived images.

The sensor systems will have to provide useful data in real time, and the analytical model will have to predict component performance. A key element of the computer system will be a storage and retrieval system that will compare on-line data for the assessment of the coating condition. Digital IR images for each blade in a row can be easily accessed and stored using frame grabbers and modern computer workstations. Only the actual hardware remains to be configured and software must developed. Also included in the system is the stored TBC/component thermal analysis database 15, TBC/component lifting database 16, sensor data/temperature/lifting on-line analysis system 17 and an expert system based operator interface output system 18. Thermal analysis database 15 is current spatial data of radiance for each blade or vane. Component life database 16 is historical spatial data of radiance for each blade or vane. Sensor/data/temperature/life on-line analysis system 17 is a system that compares current data with historical data to look for evidence of TBC failure. Expert system 18

is a system that takes evidence of failure and tests against operating conditions, determines relevance, and estimates remaining life.

The computer analysis and operator interface will be a dual-level hierarchical system shown in Figure 4. At the lower level, dedicated sensor computers 30 will monitor on-line sensor 20, an RPM sensor and per rev signal 24. The IR port 21 will provide a direct "line of sight" to the blade path. Pressure Barrier 22 will allow IR signal through to sensor system 20. Optical System 23 will allow focal length adjustment for necessary magnification. At the higher level, a supervisory computer 34 containing an advisory expert system will oversee the sensor computers 30. This supervisory system will contain knowledge that will identify an impending failure and prescribe corrective action. The supervisory computer will have two subsystems: lifting processor 26 which determines remaining life of TBC, damage and engine operating parameter processor 28 which continually monitors engine parameters like: temperature, speed, fuel consumption and power output.

Infrared transmission, absorption, and emissivity properties of the turbine engine gas will be initially calibrated within the range of operating parameters expected. Thermal emission characteristics will be determined for several "states" of the TBC condition. The characteristics will include emissivity, conductivity, and absorption as a function of temperature and wave-length. Normal changes of the TBC including sintering and contamination will be taken into account. Characteristics of deteriorating TBCs will be studied and compared to normal changes in the undeteriorated state. TBCs are subject to sintering and innocuous contamination, both of which are expected to influence measured spectral properties. Also, because TBCs have a transparent nature at the longer

wavelengths that are expected to be employed in the sensor system, the thermally grown oxide (TGO) that continually grows between the TBC and the bond coat is also expected to affect the spectral properties. These normal changes are gradual, and therefore, are expected to cause gradual and accountable changes in the emission of a normal TBC. The expert system will learn to compensate for these.

Deteriorating TBC will cause a local step change in radiance. The two primary deterioration conditions are: debonding at the TGO-to-TBC interface, and final spallation of the TBC. The debonding will be the precursor to most spallations, the exception being those caused by foreign object impact damage. The temperature of the unattached TBC region will increase as the debond grows, and the IR imaged area will also grow. At some critical size, the debonded region will spall off, exposing the cooler bond coat surface to the hot turbine engine gas, a local drop in radiance will be apparent.

Critical hot section components are commonly cooled by using cooling gases, pumped from an associated cooling system, hat travel through specific passages within the component. If the passages become ineffective for reasons like blockages, wall failure or oxidation, the component life will be diminished. Because of the concern for the failure of the cooling system, the invention described herein is also needed to monitor surface radiance changes that are directly a result of cooling system failures.

The supervisory software 34 for the whole design will store all the processed data coming from the blade through sensor 20 and the on-line temperature and lifting analysis systems. The data will be supplemented by common engine operating parameters.

Data will be processed into a meaningful form to demonstrate changes or excursions that require reporting to the control software. The control software will interpret the reported trends or excursions and notify or alert the operator of the finding. Different types of preprocessing logic will be used to identify excursions or trends. Raw data signals will be processed as collected. Some preprocessing steps will include a continually updated running average with statistical significance for ongoing data collection. This will establish a baseline for comparison of each refreshed data set. Excursions from this baseline will be brought to the attention and disposition of the expert system. Historical averages will be periodically stored for long-term trending and supervisory system disposition. The system will report information in the following categories: temperature maps, remaining life of TBC, recommendations for optimizing specific operating parameters, and emergency alert. By continually monitoring the operating conditions, the remaining life for different future operating conditions will be forecasted. The operator will have the ability to balance power output and TBC life expense rate based on advice given by the control system software. This will optimize power output and outage scheduling for maximum operator control. The system will provide alarms for critical TBC loss situations. The alarms will notify operators only in the event of eminent damage or failure. The system will also provide alarm signal outputs for connection to standard tripping control devices for the option of automatic tripping.

The present invention may be embodied in other forms without departing from the spirit or essential attributes thereof, and accordingly, reference should be made to both the appended claims and the foregoing specification as indicating the scope of the invention.

WHAT IS CLAIMED IS:

1. A method for testing a cooled, operating turbine component which will contain an exterior protective ceramic thermal barrier coating undergoing potential degradation in a corrosive high temperature turbine environment and having a low-IR reflective surface, by remote monitoring of radiant energy to determine any degradation of the cooling system, or of the thermal barrier coating, caused by at least one of erosion, corrosion, sintering, microcracking, spallation, and bond delamination; having a database means evaluate said degradation; and optionally modifying the operating parameters of the turbine based on the evaluation of the degradation.

2. The method of Claim 1, where the turbine component is a turbine blade in motion and the low-IR reflective thermal barrier coating is a zirconia based thermal barrier coating.

3. A method for generating data from non-destructive testing of a turbine component, which is contacted by a cooling medium and which will contain an exterior protective ceramic thermal barrier coating undergoing potential degradation in a corrosive, high temperature turbine environment, by:

(A) providing an infrared thermal imaging means;

(B) providing a data base means connected to the imaging means to provide a measuring system, the measuring system having at least one sensor effective to quantitatively measure and generate data by using non-destructive, remote monitoring of the surface radiance distribution, without physical contact of the thermal barrier coating, directly at the surface of the thermal barrier coating where such distributions are caused by heat flow within the thermal barrier coating;

(C) monitoring the radiance of the measuring system to determine any degradation of the cooling system, or of the thermal barrier coating, caused by at least one of erosion, corrosion, sintering, microcracking, spallation, and bond delamination;

(D) having the database means evaluate said degradation; and

(E) optionally modifying the operating parameters of the turbine based on the evaluation of the degradation.

4. The method of Claim 3, where the thermal barrier coating has a low-IR reflective surface, and the turbine component is in motion.

5. The method of Claim 3, where the thermal barrier coating has a zirconia based low-IR reflective surface so that the remote monitoring is of substantially all radiant energy with little reflective energy, and the turbine component is in motion.

6. The method of Claim 3, where the infrared thermal imaging means is an infrared camera.

7. The method of Claim 3, where the measuring system contains at least one sensor, signal processor and temperature determiner.

8. The method of Claim 3, where the sensor is a pyrometric sensor array.

9. The method of Claim 3, where the turbine component is a turbine blade rotating at speeds of from 60 to 3600 revolutions per minute and where the infrared thermal imaging means acquires a single blade image over a short time interval.

10. The method of Claim 3, where the turbine component is a turbine blade and where, in step (D), data is acquired for all blades and then correlated with previous images of each blade.

11. The method of Claim 3, where the infrared thermal imaging means is a focal plane array, imaging sensor.

12. The method of claim 3, where the database means continually updates IR radiance maps of the surface of a component.

13. The method of Claim 3, where in step (C) the measuring system only monitors radiance to detect local perturbations indicating spallation and bond delamination.

14. The method of Claim 13, where the measuring system measures the change in radiance of one specific wavelength.

15. The method of Claim 3, where the turbine component has a ceramic exterior thermal barrier coating having a low-IR reflective surface in which the contrainformational reflected component is not significant, and where the thermal barrier coating has a low-IR reflective surface of zirconia stabilized with transition metal oxides.

16. The method of Claim 3, where the turbine component has a ceramic exterior thermal barrier coating having a low-IR reflective surface in which the contrainformational reflected component is not significant, and where the thermal barrier coating has a low-IR reflective surface selected from the group consisting of yttria, scandia, ceria and magnesia stabilized oxides.

17. The method of Claim 3, where the turbine component has a ceramic exterior thermal barrier coating having a low-IR reflective surface in which the contrainformational reflected component is not significant, and where the thermal barrier coating has a low-IR reflective surface selected from the group consisting of yttria, ceria and scandia stabilized zirconia.

18. The method of Claim 3, where the turbine component has a ceramic exterior thermal barrier coating having a low-IR reflective surface in which the contrainformational reflected component is not significant, and where the thermal barrier coating has a low-IR reflective surface of a non-zirconia based material.

19. An apparatus for non-destructive testing of a moving turbine component contacted by a cooling medium which component has an exterior ceramic thermal barrier coating undergoing potential degradation in a corrosive, high temperature environment, the apparatus comprising:

(I) a measuring system comprising:

(A) infrared thermal imaging means, and

(B) database means connected to the imaging means, said measuring system being effective to remotely measure and generate data based on the radiance of temperature distributions on the moving turbine component without physical contact to detect degradation of the ceramic coating,

(II) a data base means effective to evaluate said degradation and forecast remaining life as determined by an expert system,

(III) means to modify the operating parameters of the turbine based on the evaluation of the degradation,

(IV) a means to hypothetically adjust operating parameters to optimize remaining life, and

(V) expert system means to determine the optimal operating parameters to maximize life for a given performance need.

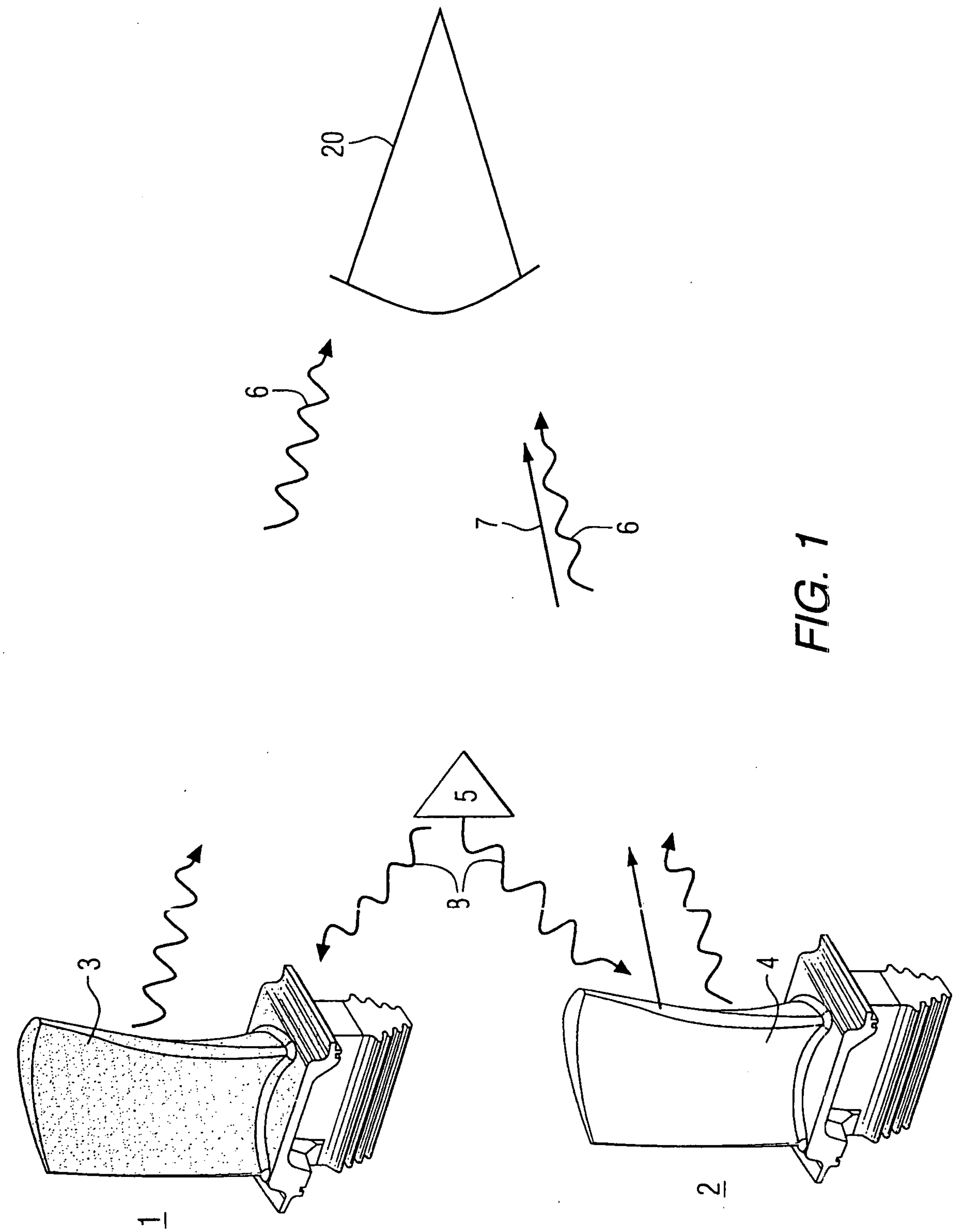
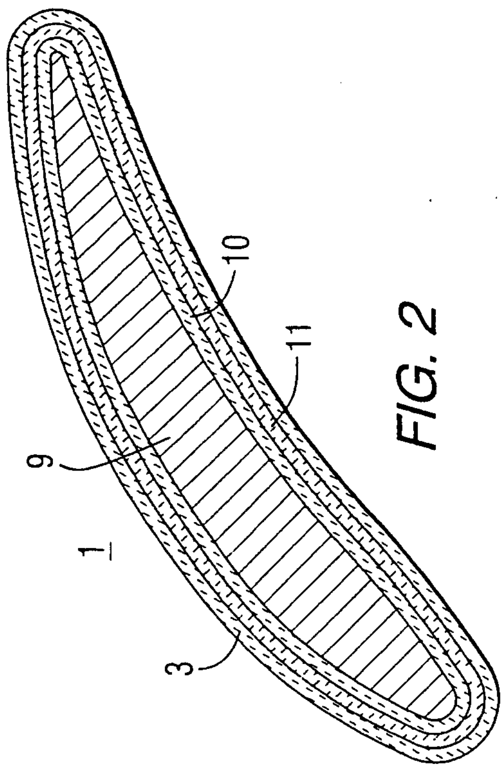


FIG. 1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3
9
10
11

FIG. 2

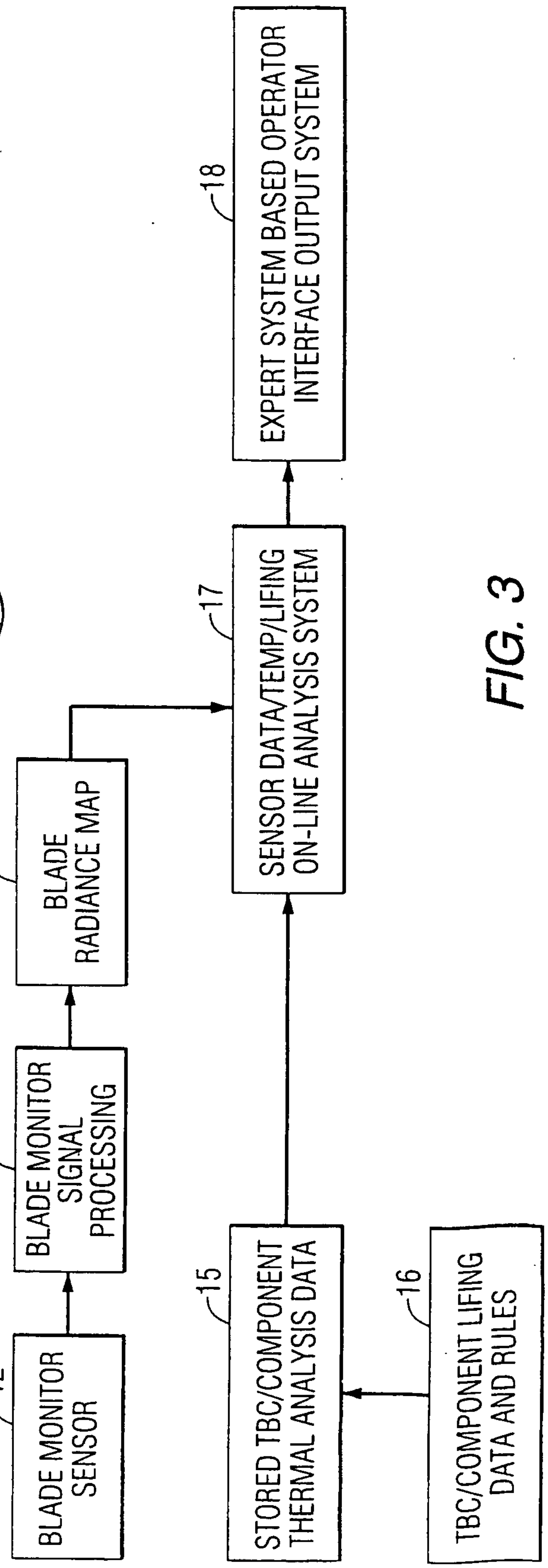
12
BLADE MONITOR SENSOR
13
BLADE MONITOR SIGNAL PROCESSING
14
BLADE RADIANCE MAP
15
STORED TBC/COMPONENT THERMAL ANALYSIS DATA
16
TBC/COMPONENT LIFING DATA AND RULES
17
SENSOR DATA/TEMP/LIFING ON-LINE ANALYSIS SYSTEM
18
EXPERT SYSTEM BASED OPERATOR INTERFACE OUTPUT SYSTEM

FIG. 3

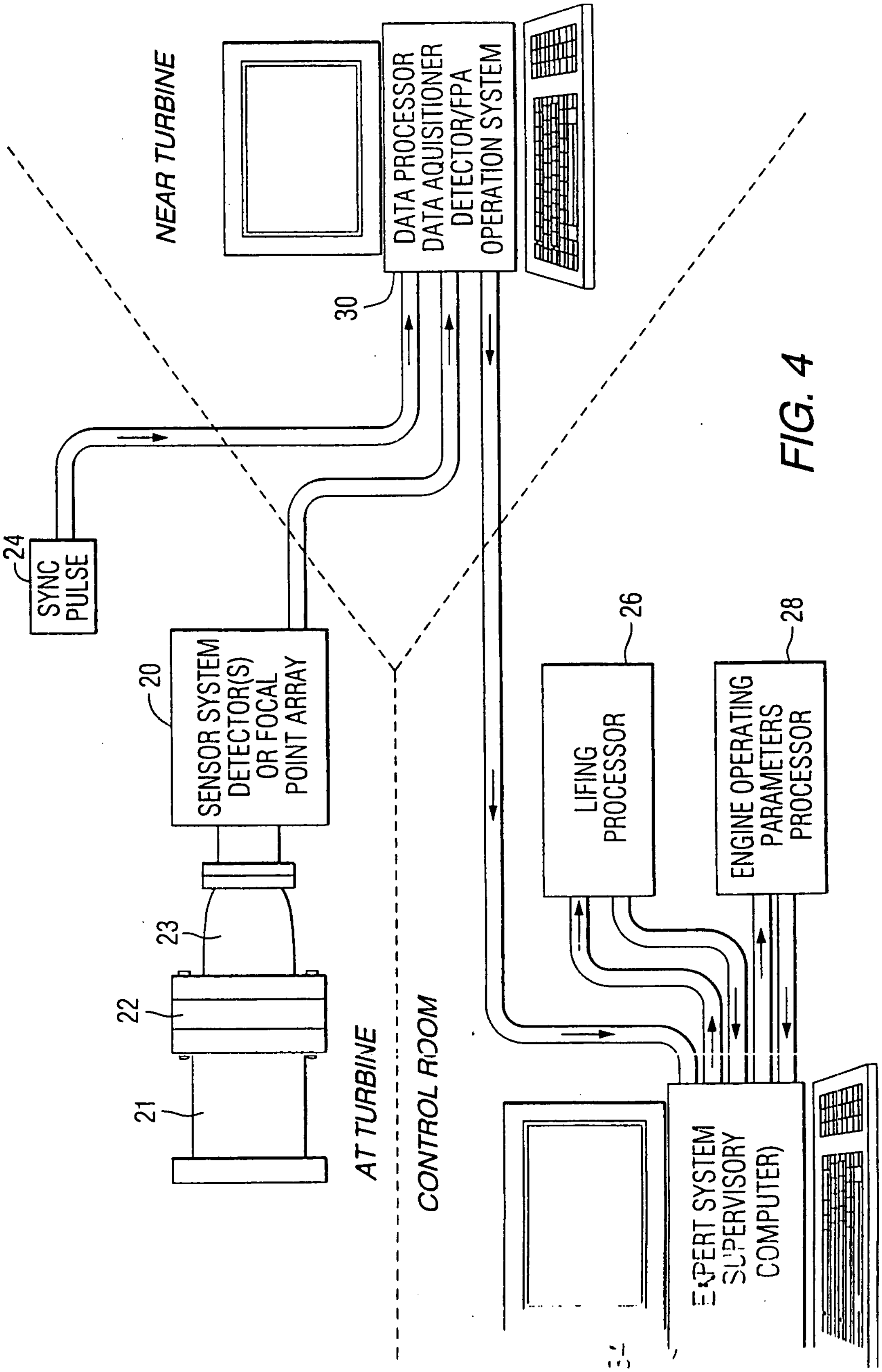
NEAR TURBINE
DATA PROCESSOR
DATA AQUISITIONER
DETECTOR/FPA
OPERATION SYSTEM
30
24
SYNC
PULSE
20
SENSOR SYSTEM
DETECTOR(S)
OR FOCAL
POINT ARRAY
23
22
21
AT TURBINE
CONTROL ROOM
26
LIFING
PROCESSOR
28
ENGINE OPERATING
PARAMETERS
PROCESSOR
EXPERT SYSTEM
SUPERVISORY
COMPUTER)

FIG. 4

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 00/33063

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01J5/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G01J G01N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 99 54692 A (ADVANCED FUEL RES INC) 28 October 1999 (1999-10-28) page 7, line 22 -page 13, line 2; figures	1,3,14, 18,19
A	DE 197 20 461 A (SIEMENS AG) 5 February 1998 (1998-02-05) the whole document	1,8,19
A	EP 0 618 432 A (EUROP GAS TURBINES SA) 5 October 1994 (1994-10-05) the whole document	1,19
A	EP 0 898 158 A (ABB RESEARCH LTD) 24 February 1999 (1999-02-24) column 8, line 48 -column 14, line 12	1,19

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
26 February 2001	14/03/2001

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